Operations Management Research
https://doi.org/10.1007/s12063-022-00270-y

Structural transformation of fuzzy analytical hierarchy process: a relevant case for Covid-19

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Received: 14 September 2021 / Revised: 23 March 2022 / Accepted: 7 April 2022

Abstract
Covid-19 has posed difficult and challenging situations to the supply chains and companies are in fix how to choose the vendors under the uncertainty and complexity in recent years. Therefore, this research aims to incorporate structural transformation of the fuzzy analytical hierarchy process (FAHP) that is most appropriate for the uncertainty and disruption caused by Covid-19 like situation for ensuring supplies from vendors. The conventional approaches for vendor selection and evaluation use numerous multi-criteria decision-making tools that may not ensure reliability in a dynamic situation caused due to Covid-19. In this research, Fleiss' Kappa method ensures the reliability of responses from eight respondents by using pairwise comparisons and assigning weights as envisaged in FAHP. In addition to determine the reliability of responses, a step under FAHP has been altered. This alteration is demonstrated in the vendor selection case in the Covid-19 scenario. The research suggests a plausible system required to address the uncertainties associated with Covid-19 to select and evaluate vendors by modifying a FAHP. The proposed altered mechanism can be incorporated in a similar type of other decision-making circumstances such as Covid-19, where the decision-makers are more than one, and the situation is very dynamic. The study is likely to facilitate information management, algorithmic development in decision making, or machine-driven decisions in uncertain conditions. The study offers managerial implications to purchase managers to accommodate and combine multiple factors and responses concerning the vendor performances for their evaluation, thus making a process more reliable.

Keywords Fuzzy analytical hierarchical process · Fleiss' Kappa · Multi-criteria decision method · Decision reliability

1 Introduction

The Covid-19 disruption resulted in the face shift of markets and how business to business (B2B) buyers and sellers interact and transact (Suguna et al. 2021). In recent years, Covid-19 has disrupted supply chains and incurred a huge loss to the economy and citizens' lives. On supply chain side, the vendors play a critical role in moving the supply chain before it reaches to customer. The Covid-19, has changed both selection and evaluation of vendors due to change in expectations, criteria's and degree of associated uncertainty. Traditionally criteria's for vendor selection is based on prices, lead times, capabilities, supplier involvement in the design (Chan et al. 2008; Ageron et al. 2013; Qian 2014; Noori-Daryan et al. 2019), work quality, negotiations, on-time delivery, and relationship management (Narasimhan et al. 2008; Mamavi et al. 2015; Scott et al. 2015; Hamdan and Cheaitou 2017; Aarikka-Stenroos et al. 2018). Vendor selection is an important activity in sourcing decision making, and it is very critical in ensuring supplies in a complex situation caused due to Covid-19. Vendor selection is a complex process since different and conflicting criteria must be considered to find competitive suppliers (Mohammed et al. 2019). The primary responsibilities of vendor managers include overseeing and facilitating the relationship between the business and its vendors and ensuring seamless supplies (Agarwal and Narayana 2020; Butt 2019; Narasimhan et al.

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Published online: 16 June 2022

2008; Wagner and Benoit 2015). Moreover, vendor managers need to coordinate purchase activities by identifying, evaluating and selecting suppliers based on various factors such as materials quality, delivery time, service, pricing, and safety as an utmost concern during Covid-19 (Rezaei and Fallah Lajimi 2019). Apart from this every organization have their own criteria, strategies and evaluation approaches to source the raw materials (Zouggari and Benyoucef 2012; Shi et al. 2015; Nair et al. 2015; Ghadimi et al. 2019). Relying on adequate means to accurately select or evaluate a particular vendor is considered as key for successful vendor management and is of strategic importance to ensure organizational performance even during complex time of Covid-19 (Govindan et al. 2015; Simić et al. 2017; Ghoushchi et al. 2018; Ketchen and Craighead 2020; Pamucar et al. 2022). The familiar saying "*by your friends, one can tell what you are*" can be expressed alternatively as "*tell us who your vendors are, and we will tell you what kind of organization is yours*" (Wagner and Benoit 2015) that is most critical in the testing times of Covid-19, where degree of uncertainty is frequently changing (Orji and Ojadi 2021). Identifying an resilient vendor in Covid-19 could be complicated (Majumdar et al. 2021), and for this reason, an accurate vendor rating technique can be an asset for vendor managers and sourcing department (Seo et al. 2018; Garzon et al. 2019; Shao et al. 2022). Strategic sourcing department within an organization may utilize different approaches available for vendor evaluation and selection of supplier available across the globe (Bals and Turkulainen 2021; Munyimi 2019). Such assessment may encourage the suppliers to improve their performance further and fit into the company's selection criteria (Bruno et al. 2012; dos Santos et al. 2019; Mohammed et al. 2019; Giannakis et al. 2020). However, despite making an effort to set up an accurate system of vendor selection, outcome may not be as expected and often lead to a group of hostile suppliers as well as insignificant big data that do not help the organization, especially in dynamic situations such as Covid-19 (Kumar et al. 2019; Mahmoudi et al. 2021). A vendor management system has no significance unless it improves vendor performance (Govindan et al. 2015; Ghoushchi et al. 2018). The vendor management system works inefficiently unless both stakeholders (manufactuer and supplier) understand the need of resilience to cope the disruptions caused by Covid-19 (Mohammed et al. 2021).

Category classification, weight point, checklist, decision matrix methods and typical multi-criteria decision-making (MCDM) tools are different vendor evaluation techniques generally used (Qian 2014; Scott et al. 2015; Simić et al. 2017). These techniques have both advantages and disadvantages, as argued in the extant literature. Velasquez and Hester (2013) have demonstrated that MCDM has been used phenomenally over several decades with increasing roles in various application areas such as e-commerce, manufacturing, and the service sector (Pratap et al. 2020). Extensive research has been conducted on integrating vendor identification, evaluation and selection based on multiple factors unique to the organization (Kim 2013; Hamdan and Cheaitou 2017; Scott et al. 2015). The existing approaches lack transparency in the inter-expert response reliability, which is critical for a complex, uncertain and dynamic situation such as Covid-19. A handful of studies also witnessed the vendor selection under the uncertainty developed due to Covid-19, but these were limited to sustainability to manufacturing or selecting a supplier to vaccine logistics or selecting a hospital for Covid-19 related care (Shirazi et al. 2020; Orji and Ojadi 2021; Yazdani et al. 2021). For instance Pamucar et al. (2022) conducted the study on supplier selection for healthcare supply chain only through novel fuzzy rough decision-making approach during Covid-19. Another study by Petrudi et al. (2021) indicate the assessment of suppliers on the basis of social sustainability innovation capabilities during Covid-19.

The existing studies lack a mechanism that offers transparency and reliability in supplier selection during Covid-19. Hence, this study made an effort to bridge the gap of transparency and reliability through structural transformation of the fuzzy analytical hierarchy process (FAHP) by employing Fleiss' Kappa, a tool used to interpret the inter-rater reliability (Ghunaim and Dichter 2019).

Moreover, the study argue for the structural transformation of FAHP method wherein multiple informants can be included in selecting a suitable vendor. In its basic form, FAHP can consider only one response through a pairwise comparison and cannot be considered with multiple respondents because of the demand to calculate the average of rated response. Hence, in the case of more than one respondent, if the estimated responses are extreme values on either side of rating scale, then probably, the mean value on the rating scale with higher deviation will be considered, thus making it irrelevant in terms of decision-making. The suggested structural change is in line with the argument by Sandberg and Alvesson (2011) that advocated the *gap spotting and problem formation*.

The present study is motivated by a discussion with the vendor manager of an organization in the automotive sector during the Covid-19 outbreak. The vendor manager responded to an open-ended question: *how the organization rates its vendors?*. In the reply, vendor manager shared some criteria used in their organization to evaluate vendors especially during Covid-19 situation. He mentioned that they often find it difficult when multiple raters who assess vendors differ in their opinions regarding the same criteria. Hence, the process of the vendor rating gets stalled with no-decision. This situation has motivated the current study, which proposes an incremental transformation to a FAHP by illustrating it on vendor rating decisions during uncertain times of Covid-19. Hence, this study attempts to bridge the gap between ratings provided by multiple raters and arrive at a reliable ranking by accommodating multiple raters. The proposed structural transformation can be adapted by the organizations to select the vendor with more than one evaluator.

The remaining part of the paper is organized as follows: The next section presents the review of literature highlighting FAHP, AHP, MCDM techniques, along with some recent ones in the vendor selection domain. Section 3 delineates the research design where goals, criteria, and alternatives are described along with the suggested modification in the FAHP application. Section 4 presents the data analysis through appropriate and structurally transformed FAHP. Section 5 discusses the findings along with implications for theory and practice. Lastly, conclusions are drawn in Sect. 6.

2 Literature review

Purchasing is a core function of an integrated supply chain responsible for reliable supplies of materials (Kim 2013). The efficiency of supplies is directly proportional to the supplier capabilities right from information technologies used to operational capabilities (Irfan et al. 2019). Therefore, the selection and management of suppliers become critical for the purchasing and sourcing strategy of a company (Rossetti and Choi 2005; Shook et al. 2009). Suppliers are the first and critical layer that helps design the supply chain strategies because it supports directly purchasing managers on the cost-saving and quality front (Olhager and Selldin 2004; Hitt 2011; Gelderman et al. 2020). The function of purchasing is identifying, evaluating, selecting and keeping an eye on them in terms of their well-being and developing them to have multiple capabilities (Rehme et al. 2013; Walker et al. 2014). Purchasing function is responsible to make a balance between supply risk and its impact on the financial performance of an organization (Avery et al. 2014; Li et al. 2015). For routine and regular products, purchasing managers can opt for systematic contracting due to various products and highly complex logistic activities (Andersson and Norrman 2002). Supplies, where suppliers are monopolistic, need to ensure a secured supply chain and easily assessable alternatives (Schwenen 2014). Purchasing professionals need to be careful while screening the supplier proposals to have minimal supply chain risk while ensuring the high impact on financial performance in the era of uncertainty such as Covid-19 (Avery et al. 2014; Orji and Ojadi 2021; Shirazi et al. 2020). A performance-based partnership with suppliers is recommended for strategic products (Hoffmann et al. 2013; Bals et al. 2019).

Apart from the typical selection criteria for suppliers, other parameters are also critical for purchasing function. These parameters include earlier contact, providing other raw-material, evaluation based on price quotation, and the supplier's financial status (Giannakis et al. 2020). Additionally, reference check, visit to supplier premises, audit, and testing of their processes are conducted to complete the supplier selection process by the purchasing function (Lari 2002). In this way, purchasing department help developing the confidence in the supply chain from the supplier capability perspective for a particular raw material (Sarkar and Mohapatra 2006; Sancha et al. 2015). Traditionally purchasing function has been using numerous supplier selection methods ranging from cost ratio to linear average (De Boer et al. 2001; Ordoobadi and Wang 2011). Compared to traditional settings, for Covid-19 like situations, sustainability, transparency and reliability are more important (Dubey et al. 2021; Mahmoudi et al. 2021). Firms in the past have also used knowledge-based sourcing to select and pull supplies from vendors (Choy et al. 2005). Other studies advocate the supplier selection on the basis of associated risk, skills of supplier's employees and value offered to the buyer etc. (Dubey et al. 2018a; Gelderman and Semeijn 2006; Brito and Miguel 2017). The studies also focus on evaluating the suppliers on the basis of their capability of providing green materials and incorporating sustainable operations (Majumdar et al. 2021; Schulze et al. 2022; Shao et al. 2022).

Apart from raw-materials, there are other suppliers who help to run the production of a company such as insurance provider for critical equipment in the production plant (Tracey and Tan 2001). Due to the fact that sixty to seventy percent of the product cost incurred lies in raw materials, therefore purchasing role becomes strategically important. Moreover, the strategic decisions by purchasing function impact the objectives of a business and becomes even critical when operate under uncertainty (Adobor and McMullen 2014; Agarwal and Narayana 2020). Purchasing executives need close coordination with other departments to successfully integrate stakeholders including vendor into the firm's vision (Luzzini and Ronchi 2011). The integrative approach can facilitate the development of a new model that can address the disruptions and degree of reliability required during uncertain times of Covid-19.

Vendor selection is a group decision-making process involving several cross functions in an industrial setting (Chou and Chang 2008). As argued by Heizer and Render (2001), the right source provides the right quality and price of materials at the right time. Verma and Pullman (1998) have indicated that vendor selection is based on the relative importance of various approaches. In the past, researchers have reviewed and analyzed vendor selection criteria and methods (Weber et al. 1991; Chai et al. 2013; Velasquez and Hester 2013). A study by Dickson (1966) has suggested that supplier selection encompasses multiple factors and is a multiple objective decision. Kahraman et al. (2003) have described the identification of suppliers who can meet organizations' needs consistently at moderate costs as an objective. In the recent decades, technological capability has also emerged as one of the critical criteria for supplier selection. In this regard, Velasquez and Hester (2013) have asserted that advancements in technology over the past few decades have led to the emergence of sophisticated analysis methods.

Additionally, the MCDM technique has developed novel approaches toward decision analysis. Examples of such investigations are the additive utility formulations reviewed by Fishburn (1967), Keeney and Fishburn (1974) and Keeney (1977). For instance, the linear weight model by Weber et al. (2000) that assign weight to a criterion under consideration. Chai et al. (2013) have reviewed decision approaches by classifying them into six different categories indicate the analytical hierarchy process (AHP) as one of the widely used decision-making tool. AHP technique has been complemented with the goal programming in product lifecycle by Kull and Talluri (2008). Other studies employed different techniques. For instance, the hybrid AHP by Sevkli et al. (2008), a fuzzy hierarchical technique for order of preference by similarity to ideal solution (TOPSIS) by Wang et al. (2009), the Taguchi loss function by Ordoobadi (2010), an interval-valued pairwise comparison in FAHP by Chamodrakas et al. (2010), fuzzy linguistic expression by Labib (2011), weighted max–min fuzzy decision model by Amid et al. (2011), and the integration of multiple techniques by Zeydan et al. (2011). To further deepen the litertare analysis and its findings, Table 1 describes the literature review on supplier selection that offer enough space for structural transformation of the FAHP.

Discussing about AHP, it is a measurement technique (Saaty 2008) that performs pairwise comparisons among factors based on the judgments of experts followed by a specified direction to get the factor priorities. Dyer (1990) has argued that the adequate use of AHP requires a synthesis with the concept of multi-attribute utility theory. AHP allows inconsistencies in pairwise judgment (Bruno et al. 2012). Further, Bottani and Rizzi (2005) have advocated combining the fuzzy approach with AHP and have allowed decision-makers to express ill-defined judgments. To identify the barriers of information technology applications in the supply chain system of sugar industry, Kumar and Kansara (2018) considered AHP and FAHP to develop the rank correlation of both techniques to identify the ranking similarity. Additionally, Kumar and Garg (2017) evaluated sustainable supply chain indicators using fuzzy AHP. Basset et al. (2018) employed an integrated neutrosophic AHP and SWOT method for strategic planning. For assessing the critical success factors of supplier development, Routroy and Pradhan (2013) used the FAHP. However, most of the studies are limited in exploring the vendor identification and evaluation in traditional setting; hence it develops a gap for this study to develop and indicate a approach suitable for supplier selection under uncertainty situation such as Covid-19.

Discussing about fuzzy theory, it is argued in set theory (Chen et al. 2001) that an individual is either a member or not a member of "set", and the fuzzy theory is a "natural extension" to the set theory. The classical set theory advanced to fuzzy theory (Zadeh 1965, 1997). Zadeh (1997) has described granulation, organization, and causation as concepts that form the basis for human cognition and approximated fuzzy logic to "computing with words". Decomposition is postulated as granulation, thus integrating parts of an organization into a whole, and causation associates cause with effects. In FAHP, fuzzy logic determine the weights of criteria selected by decision-makers and ranking of the measure discovered. Table 2 summarize variants of the fuzzy AHP methods devised by numerous authors based on the fuzzy set theory (Zadeh 1965). However, when it comes to using the method in managerial decision making like supplier selection, literature lack in throwing a light on modification requirements, if any, to make it suitable where a group of individuals is involved and situation is uncertain. Simulating a decision-making process in contemporary concepts like artificial intelligence or machine learning requires an initial algorithmic representation of the process (Wamba et al. 2020). Thus, by incorporating the appropriate research methodology described next, this study made an effort to bridge this gap of structural transformation of FAHP.

3 Research design

A combination of case study and experiment is used as the research methodology because a formal decision-making tool in FAHP with suggestive modification is proposed and illustrated on the supplier selection problem. Timmermans (1991) has introduced outcome criteria, process criteria, and practical criteria for decision model evaluation. Additionally, the author has suggested 'technical' measures such as data availability, uncertainty level along with other alternatives. Hence, building on research by de Boer & van der Wegen (2003), a modified FAHP is validated on vendor selection case keeping uncertainty and agility in mind required due to Covid-19 (Dubey et al. 2018b). A case study is incorporated to illustrate the actual decision-making process of vendor selection. A discussion with the personnel responsible for evaluating vendors has revealed that numerous individuals in the departmental hierarchy rate vendors. It can lead to ambiguous situations, for example, when the rater's ratings present extreme values, such as 3 and 9 on a Saaty Scale that provide an average of 6 with a deviation of 3 to both the sides of the mean. The suppliers' rank calculated based

Table 1 Review of recent literature on supplier selection

Author(s) and Year	Research Objective	Level of analysis	The technique used in the analysis	Approach adopted	Setting	Major Findings
Gupta et al. (2019)	Greens supplier selection under fuzzy environment	Firm	Fuzzy AHP, TOPSIS, MABAC, and WASPS	Case study	Automotive Industry from India	The study utilized a weighted sum and product model in WASPAS. The three hybrid models (Fuzzy AHP and TOPSIS, Fuzzy AHP and WASPAS, Fuzzy AHP, and MABAC) exhibit the same results of green supplier selection
Alkahtani et al. (2019)	Evaluation of supplier selection approaches	Firm	Fuzzy AHP and TOPSIS	Case study	Chemical manufacturer from Saudi Arabia	Six criteria have considered while evaluating these methods. Findings indicate that AHP performs better than fuzzy TOPSIS in terms of computational complexity, whereas fuzzy TOPSIS is best suited to ensure agility is the process of decision making
Kumar et al. (2019)	An integrated approach for supplier selection	Firm	Taguchi loss function, AHP, and TOPSIS	Case study	Indian Railways	Out of four criteria (Quality, price, delivery, and service level). Two separate cases (pipe suppliers and ball bearing suppliers) have described and propose a balance model through pricing and service levels
Zhang et al. (2019)	Private partner selection for electric vehicles	Firm	VIKOR	Case study	E-Vehicle Charging Infrastructure in China	VIKOR results are determined subjectively through decision-makers, and this leads to uncertainty in results. Hence, the intuitionistic fuzzy set employed along with information entropy and used to obtain actual weight. It helps in the reduction of subjectivity specifically for qualitative indicators
Jain et al. (2018)	Supplier selection	Firm	Fuzzy AHP and TOPSIS	Case study	The automotive firm from India	The comparison of AHP and TOPSIS with fuzzy AHP and TOPSIS indicates that fuzzy approaches can be more accurate and useful for supplier selection problems

Table 1 (continued)

Author(s) and Year	Research Objective	Level of analysis	The technique used in the analysis	Approach adopted	Setting	Major Findings
Sureeyatanapas et al. (2018)	Supplier selection in an uncertain environment	Firm	Extended TOPSIS	Case study	Egg supplier to a restaurant in Thailand	Based on five criteria, the suppliers are ranked on assessment grades through A to D. Further, with the help of ranking order criteria, the supplier selection suggested using an interval form of the information, where the judgments of decision-makers minimized
Polat et al. (2017)	Supplier selection	Firm	Fuzzy AHP and TOPSIS	Case study	Railways from Saudi Arabia	Out of the eight criteria's three were found very important and critical those carry maximum weightage. For instance, the total cost of the product and technical expertise of the supplies and lead time in which they operate is crucial for selecting a supplier

The Table 1 consist the review of an articles that employed some type of multi criteria decision making tool in the supplier selection decision. The reviews substantiate the research gap of using the structural transformation of the fuzzy AHP for supplier selection

Table 2 Variants of fuzzy AHP and their application

Author/s	Contribution
Van Laarhoven and Pedrycz (1983)	Compared the fuzzy ratios by a triangular membership function
Buckley (1985)	Determined the fuzzy priorities of comparison ratios by trapezoidal membership functions
Stam et al. (1996)	How artificial intelligence used to approximate the preference rating in the AHP
Chang (1996)	The approach to fuzzy AHP by the use of triangular-fuzzy members for pair-wise comparison and then using the extent analysis for the synthetic extent values of the paired comparison
Cheng (1997)	Proposed the new algorithm of fuzzy AHP using the grade value of the membership function for evaluation of naval missile system
Weck et al. (1997)	Added the mathetics of fuzzy logic to classic AHP to evaluate production cycle alternatives
Kahraman et al. (1998)	Used a fuzzy objective-subjective method to obtain the weights from the AHP and made the fuzzy weighted evaluation
Cheng (1999)	Proposed new AHP based on the linguistic variable weights

The Table 2 above describes various application of the Fuzzy AHP as emerged from the literature. The reviews substantiate the research gap of using the structural transformation of the fuzzy AHP for supplier selection

on such ratings may be misleading. Hence, this research attempts to bridge such a gap between ratings provided by multiple raters and arrive at a reliable ranking by accommodating multiple respondents as raters. Figure 1 below represents the research process that helps answer the research question of "*how to adapt various raters and arrive at reliable rankings of the suppliers*"?.

In the experiment conducted for this study, the responses of eight raters are considered for pairwise

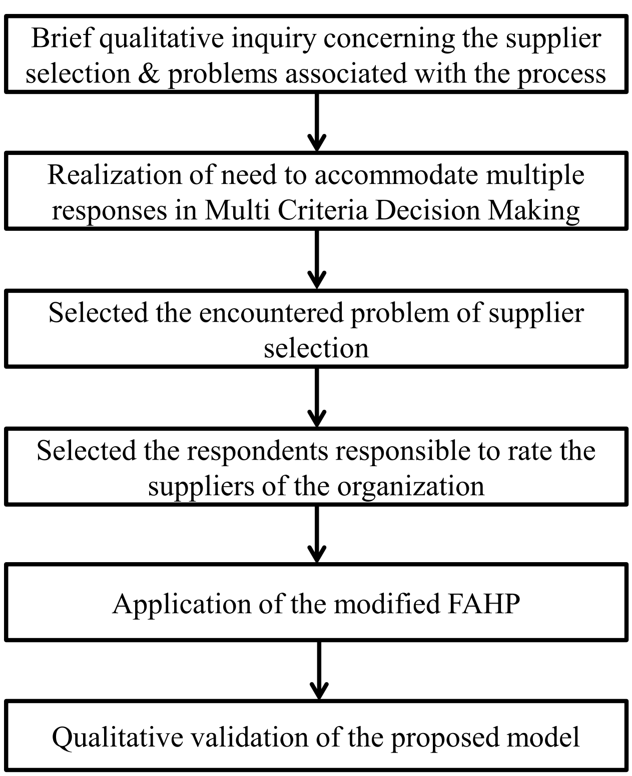

Fig. 1 The research process

comparison as envisaged under FAHP as fuzzy responses. The Kappa value for agreement between the raters for a given paired comparison is calculated. If the Kappa value satisfies a particular condition, it is followed by a FAHP analysis. This step is proposed considering the average value of responses from multiple respondents that may not adequately represent the reactions of raters due to relatively high standard deviation. The implications of the proposed methodological modification are grounded to the existing theory. Figure 2 presents the decision-making hierarchy, whereas Fig. 3 indicates that the unit of analysis in the case illustration is suppliers and the multiple raters are the respondents. Further, Fig. 4 illustrates the proposed modification.

3.1 Fuzzy analytical hierarchy process

This sub-section indicate the nine steps to perform the FAHP and are arranged as follows:

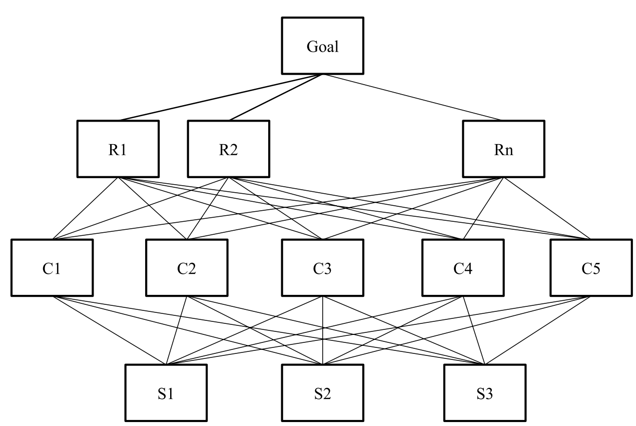

Fig. 2 An illustrative decision-making hierarchy

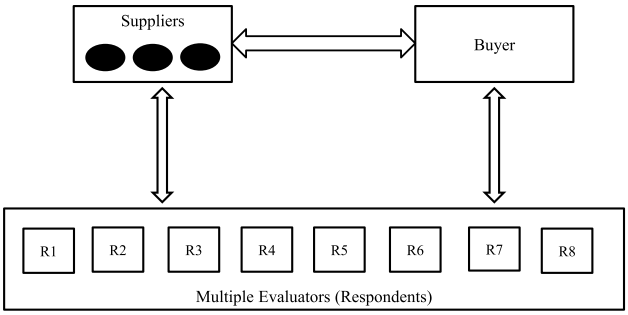

Fig. 3 The unit of analysis

Step 1: Compare the criteria or alternatives using linguistic variables shown in Table 2. If the respondent assigns a fuzzy triangular scale (4, 5, 6) to the given comparison, then the contribution matrix of that pair shall take (1/6, 1/5, 1/4) as its fuzzy value.

$$\tilde{A}_k = \begin{vmatrix} (1,1,1) & \tilde{d}^k_{12} & \tilde{d}^k_{13} & \ldots\ldots & \tilde{d}^k_{ln} \\ \tilde{d}^k_{21} & (1,1,1) & \ldots\ldots & \ldots\ldots & : \\ \tilde{d}^k_{31} & : & (1,1,1) & \ldots\ldots & : \\ : & : & : & .. & : \\ \tilde{d}^k_{nl} & : & \ldots\ldots & \ldots\ldots & (1,1,1) \end{vmatrix}$$

Step 2: If the number of respondents is more than one, calculate the mean of the weights assigned by the multiple respondents, as proposed by Buckley (1985).
Step 3: Calculate the geometric mean of each criterion's fuzzy comparison values, as shown in the following equation (ibid):

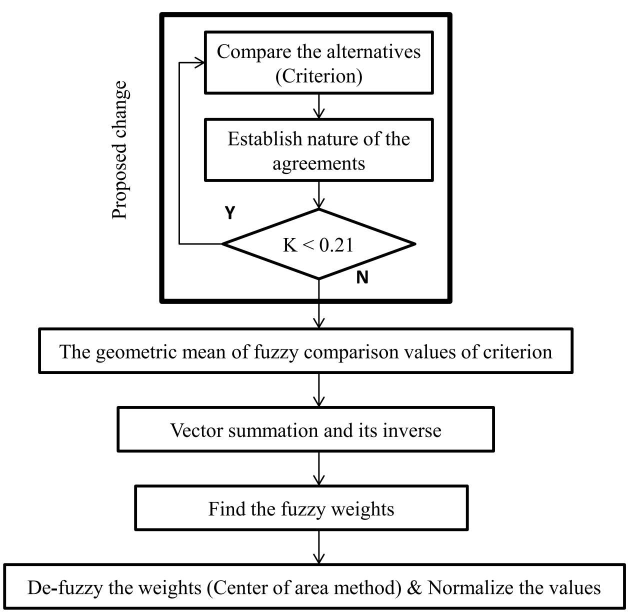

Fig. 4 The proposed modification in the initial steps of FAHP is highlighted

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij} \right)^{1/n},$$

For $i = 1, 2\ldots n$.
Step 4: Perform vector summation.
Step 5: Calculate the inverse power of each summation vector and replace the fuzzy triangular number by arranging it in increasing order.
Step 6: Calculate the fuzzy weights by using the following equation:

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1}$$

Step 7: Calculate lw_i, mw_i, nw_i.
Step 8: Since the 'w' is triangular, de-fuzzy it using the centre of area method (Chou and Chang 2008).
Step 9: Normalize the values.

3.2 The suggestive structural transformation in FAHP

This sub-section indicate the three steps of structural transformation in FAHP and are arranged as follows:

Step 1: Replace the scale used in Step 1 under Sect. 4 with the Saaty scale and record the weights assigned by the multiple respondents (Refer to Table 2).
Step 2: Employ Fleiss' Kappa technique to establish the nature of the respondents' agreement for comparing the pairs (items), which states that the rater agreement should be at least at the reasonable level of $K = 0.21$ and above. For $K < 0.21$, reassignment of weights by respondents is expected. This step is proposed considering that the average value of responses from multiple respondents may not adequately represent the reactions.
Step 3: Considering the n responses as fuzzy weights repeat Step 3, as stated in Sect. 3, to arrive at the normalized ratings.

3.3 Illustration of structural transformation in FAHP

This study, considers the automotive sector organization who required to rank three suppliers. Rankings are based on the following factors: *quality of the supply based on rejection rate*, *supplier location*, *the unit price offered*, *the delivery time considered from the moment the order was raised to the moment it finally reached*, and *after-sales services such as collection and replacement of the rejected materials*. The organization has considered three suppliers for evaluation because they are predominant suppliers of a specific category of materials. The sourcing department of the considered organization comprised of multiple evaluators.

Table 3 The rating received from the eight respondents for the pairwise comparison of the factors under consideration

	Categories (AHP Scale)								
Items/ Pairs	1	2	3	4	5	6	7	8	9
1/ Quality-Location	2	0	6	0	0	0	0	0	0
2/ Quality-Cost	0	0	0	0	0	0	4	0	4
3/ Quality-Delivery	0	0	0	0	0	1	4	3	0
4/ Quality-After sales service	0	0	0	1	4	2	1	0	0
5/ Location-Cost	0	0	0	0	4	3	1	0	0
6/ Location-Delivery	0	0	0	0	0	0	1	3	4
7/ Location-After sales service	0	0	0	0	0	2	4	2	0
8/ Delivery-Cost	1	2	5	0	0	0	0	0	0
9/ Cost-After sales service	0	0	4	2	2	0	0	0	0
10/ Delivery-After sales service	0	0	0	0	0	1	6	0	1

Table 3 interpreted as for item pair numbered one, two respondents rated the pair importance as one and six respondents rated as 3. Similar interpretation expected for the remaining item pairs

Table 4 Aggregation of the matrices provided by each respondent for the criterion comparison

	Quality							
Quality	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Location	0.33	0.33	0.33	1.00	0.33	0.33	0.33	1.00
Cost	0.14	0.17	0.14	0.20	0.14	0.14	0.20	0.11
Delivery	0.14	0.17	0.14	0.13	0.11	0.13	0.14	0.17
After Sales Service	0.17	0.20	0.20	0.14	0.20	0.17	0.20	0.25
	Location							
Quality	1.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00
Location	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cost	0.20	0.20	0.14	0.17	0.14	0.17	0.20	0.25
Delivery	0.13	0.14	0.11	0.14	0.14	0.13	0.14	0.17
After Sales Service	0.17	0.20	0.14	0.14	0.11	0.13	0.14	0.17
	Cost							
Quality	9.00	5.00	7.00	7.00	5.00	7.00	6.00	7.00
Location	4.00	5.00	6.00	7.00	6.00	7.00	5.00	5.00
Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Delivery	2.00	3.00	4.00	2.00	3.00	4.00	3.00	4.00
After Sales Service	0.33	0.20	0.33	0.20	0.33	0.25	0.33	0.50
	Delivery							
Quality	6.00	7.00	8.00	9.00	8.00	7.00	6.00	7.00
Location	6.00	7.00	8.00	7.00	7.00	9.00	7.00	8.00
Cost	0.25	0.33	0.25	0.33	0.50	0.25	0.33	0.50
Delivery	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
After Sales Service	4.00	5.00	6.00	5.00	5.00	7.00	6.00	5.00
	After Sales Service							
Quality	4.00	5.00	6.00	5.00	7.00	5.00	5.00	6.00
Location	6.00	7.00	8.00	9.00	7.00	7.00	5.00	6.00
Cost	2.00	3.00	4.00	3.00	5.00	3.00	5.00	3.00
Delivery	0.20	0.17	0.14	0.20	0.20	0.17	0.20	0.25
After Sales Service	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4 provides the rating responses to each criterion by each of the totals of eight respondents

Table 5 GM of fuzzy comparison values

	1	2	3	4	5	6	7	8
Quality	2.93	3.5	3.99	3.94	3.09	3.74	3.52	3.88
Location	2.17	2.41	3.29	3.38	3.12	3.38	2.81	2.99
Cost	0.43	0.51	0.46	0.51	0.55	0.45	0.58	0.53
Delivery	0.37	0.41	0.39	0.37	0.39	0.4	0.41	0.49
After Sales Service	0.52	0.53	0.56	0.46	0.52	0.52	0.56	0.64
Σ	6.42	7.36	8.69	8.65	7.67	8.49	7.89	8.53
Σ^{-1}	0.16	0.14	0.12	0.12	0.13	0.12	0.13	0.12
Σ^{-1}<	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.16

Hence, eight officials are considered in this study; they are experts in sourcing and category management and qualified buyers to participate in this evaluation (Schulze et al. 2022; Shook et al. 2009). Their responses are recorded by comparing them pairwise and rating the pairs using the Saaty scale.

4 Data analysis

This section indicate the process of data analysis and finally how the supplier is selected through suggestive structural modification using fuzzy AHP. Data analysis is done according to the 11 steps stated in Tables 3 to 12.

Steps 1 and 2: Finding the Kappa value (K) and checking it for the agreements between the eight respondents/raters. Table 3 demonstrates the ratings received from eight respondents for the pairwise comparison of the factors under consideration.

Of the eight respondents, the lowest ratings for "Quality-Location" comparison, that is, "1" and "3," are given by respondents two and six respectively; the other ratings were calculated similarly. The estimated K value equals 0.2531, thus signifying a fair inter-rater agreement.

Step 3: Considering the n responses (8 in the case) as the fuzzy weights, the regular FAHP steps are followed in Table 4.

Step 4: Calculate the geometric mean, as provided in Table 5.

Step 5: Fuzzy and normalized weight calculation (the normalized values are provided in Table 6).

Table 6 Calculate fuzzy weights of each criterion, its average, and normalized weights

	Weights								Average	N*
Quality	0.34	0.4	0.47	0.46	0.39	0.49	0.48	0.61	0.45	0.45
Location	0.25	0.28	0.39	0.4	0.4	0.44	0.38	0.47	0.37	0.37
Cost	0.05	0.06	0.05	0.06	0.07	0.06	0.08	0.08	0.06	0.06
Delivery	0.04	0.05	0.05	0.04	0.05	0.05	0.06	0.08	0.05	0.05
After Sales Service	0.06	0.06	0.07	0.05	0.07	0.07	0.08	0.1	0.07	0.07

*N** normalized weight

Table 7 Comparing alternatives w.r.t. Criteria quality by the eight respondents

	S1							
S1	1	1	1	1	1	1	1	1
S2	4	5	6	7	5	5	3	5
S3	9	9	9	7	8	9	7	6
	S2							
S1	0.2	0.33	0.2	0.2	0.14	0.17	0.2	0.25
S2	1	1	1	1	1	1	1	1
S3	2	3	4	5	3	2	3	3
	S3							
S1	0.17	0.14	0.11	0.13	0.14	0.11	0.11	0.11
S2	0.33	0.33	0.5	0.33	0.2	0.25	0.33	0.5
S3	1	1	1	1	1	1	1	1

Table 8 Geometric mean of fuzzy comparison values w.r.t. Criteria quality by the eight respondents

S1	0.32	0.36	0.28	0.29	0.27	0.26	0.28	0.3
S2	1.1	1.19	1.44	1.33	1	1.08	1	1.36
S3	2.62	3	3.3	3.27	2.88	2.62	2.76	2.62
Σ	4.04	4.55	5.03	4.89	4.16	3.96	4.04	4.28
Σ^{-1}	0.25	0.22	0.2	0.2	0.24	0.25	0.25	0.23
$\Sigma^{-1} <$	0.2	0.2	0.22	0.23	0.24	0.25	0.25	0.25

Step 6: Find K and check it for the agreements between the eight respondents.

The K values are "fair" while comparing alternatives relevant to the entire criteria.

Step 7: Compare individual criteria. Table 7 presents the results related to quality criteria.

Step 8: Compare geometric mean. Table 8 displays quality criteria comparison.

Step 9: Evaluation of fuzzy weights for each alternative (Table 9).

Similarly, normalized weights for location, cost, delivery, and after-sales service criteria can be obtained by following steps 7 to 9.

Step 10: Obtain normalized weights for each criterion and alternative. Table 10 displays the steps used by repeating steps from 7 to 9.

Step 11: Final alternative selection calculations. Tables 11 and 12 display the estimates.

5 Discussion

Rohrmann (1986) has proposed a methodology to evaluate decision models and has suggested the quality of decision, benefits, economy, practicability, and user satisfaction as its evaluation criteria. The supplier selection model and its evaluation framework of De Boer and Van der Wegen (2003) have indicated two dimensions, that is, "Complexity fit" and "Cost versus Benefit," and critically has examined the model based on various criteria's. The literature on MCDM suggests several strategies for supplier selection. In the decision model for supplier selection, the adequate tool of structural transformation of FAHP is introduced with some suggestive modifications for decision-makers. Thus, a combination of case study and structural transformation is applied. The case study offers a complete visualization of the actual decision-making process of suppliers' ranking and the possibilities to facilitate information management, algorithmic development

Table 9 Fuzzy weight of each alternative w.r.t. Quality, its average weight, and normalized weights

	Weight								Average Weight	Normalized Weight
S1	0.06	0.07	0.06	0.07	0.07	0.07	0.07	0.08	0.07	0.07
S2	0.22	0.24	0.32	0.31	0.24	0.27	0.25	0.34	0.27	0.27
S3	0.52	0.61	0.73	0.76	0.69	0.65	0.68	0.66	0.66	0.66

Table 10 Normalized relative weights of each alternative for each criterion

	Quality	Location	Cost	Delivery	After Sales Service
S1	0.07	0.13	0.06	0.08	0.08
S2	0.27	0.3	0.31	0.35	0.35
S3	0.66	0.57	0.66	0.46	0.46

Table 11 Scores of alternatives concerning criteria

	Weights	S1	S2	S3
Quality	0.45	0.07	0.27	0.66
Location	0.37	0.13	0.3	0.57
Cost	0.06	0.06	0.31	0.66
Delivery	0.05	0.08	0.35	0.46
After Sales Service	0.07	0.08	0.35	0.46

Table 11 onsists of separate vectors in the form of criterion weights, and alternatives (supplier) weights for each of the criteria

Table 12 Framework for supplier selection models evaluation (de Boer and van der Wegen 2003)

Dimensions	Criteria
Complexity-fit	C1: Does the model aggregate information in a proper way?
	C2: Does the model sufficiently utilize available information?
	C3: Is it (to a satisfactory extent) possible to incorporate opinions and beliefs?
	C4: Is it (to a satisfactory extent) possible to achieve fair participation of individual members in case of a group decision?
	C5: Is the model sufficiently flexible for changes in the decision situation?
Cost /benefit	C6: Is the outcome of the decision model useful?
	C7: Is the outcome of the decision model acceptable?
	C6: Are the required investments justifiable?
	C9: Is the model sufficiently user-friendly?
	C10: Is the way the decision model works sufficiently clear?
	C11: Does the decision model increase the insight into the decision situation?
	C12: Does the decision model contribute to the communication about and the justification of the decision?
	C13: Does the decision model contribute to your decision-making skills?

Table 12 shows Framework for Supplier Selection Models Evaluation as suggested by (de Boer and van der Wegen 2003). The proposed structural change to the FAHP is applied to the supplier selection case and an attempt has been made to validate the model based on the said framework

in decision making, or machine-driven decisions of similar types of uncertain situations.

5.1 Implications for theory

Implementing a FAHP-based methodology to evaluate the suppliers leads to interesting implications and comments. Its strength lies in aggregating the information through hierarchy and decomposition, thus satisfying Criteria 1 indicated in Table 12. The proposed FAHP-based model uses data efficiently (Criteria 2 in Table 12) and allows qualitative evaluation of parameters (Criteria 3 in Table 12). The structural transformation model attempts to achieve fair participation of members in a group by ensuring interaction between the researcher and respondents. All judgments depend on the views of multiple respondents, and this is subject to the agreement between them. Furthermore, using aggregation methodology by considering responses as fuzzy can significantly control the variance in the weights assigned to the respective criteria. It can facilitate machine-driven decision making as well.

The *flexibility* of the model, as stated in Criteria 5 (Table 12), is asserted as the supplier selection can be customized to the requirements of a specific criterion. It proves that although the literature (Dickson 1966; Weber et al. 1991; He et al. 2008) has proposed comprehensive sets, it is possible to identify the attributes fit to evaluate suppliers belonging to different categories. The study of Craighead et al. (2020) indicate the present status of supply chain research from the perspective of the pandemic, but do not cover the structural transformation part.

Regarding 6th and 7th criteria of *usefulness* and *acceptability* (Table 12), it is observed that the final rank calculated may not be so useful, and firms may refuse to use such tools, because these tools may not satisfy their requirements. Organizations those need to implement supplier ranking and selection problems may choose qualitative methodologies based on experts opinion, as argued by De Boer and van der Wegen (2003). The proposed method may be useful and acceptable because of its flexibility in terms of criterion adoption. Using a qualitative approach in supplier selection can be advantageous in terms of *costs* as envisaged in Criteria 8 (Table 12). The proposed method requires minimal time to interview the respondents and record weights, thus following Criteria 9 (Table 12). The *clear* (Criteria 10 in Table 12) structure of the FAHP helps in improving buyers' and suppliers' knowledge. Implementing this approach can provides new insights for making supplier-oriented decisions more accurately (Criteria 11 in Table 12). The involvement of multiple respondents transforms a supplier evaluation problem into a strategic supplier selection tool. Thus, it contributes to *communicating* and *justifying* purchasing decisions (Criteria 12 in Table 12) and upgrades the decision-making skill requirements (Criteria 13 in Table 12). It can motivate both suppliers and buyers to improve their respective performance. In summary, the contribution of the study lies in developing a structural transformation of FAHP that is most appropriate for the uncertainty and disruption caused by Covid-19.

5.2 Implications for practice

The proposed structural transformation of FAHP may influence the buyer–supplier relations to go beyond the mere buyer–supplier association. Further there is possibility of a continuous realignment of suppliers' goals to the buyers' and vice-versa while applying the suggestive structural transformation. Orientation of the policies to evaluator and suppliers can be mapped through the indicated methodology in this study. The performance of the supply chain can be improved indirectly, when well define set of criteria's and a process of evaluation as advocated in this study is applied. The suggested structural transformation approach of FAHP can help purchasing and sourcing managers to identify, evaluate and select the potential suppliers and eliminate the weaker ones. The proposed model also support the involvement of the supplier right before the design is ready. The accuracy of analysis and ranking of a supplier can be ensured with structural transformation approach. Additionally for suppliers, this model challenge to upgrade their systems to match the expectations of the buyer. The better optimization of alternatives can be obtained while evaluating suppliers in uncertainty. The structurally transformed FAHP moreover offer an easy to understand and transparent approach for sourcing professionals.

5.3 Limitations and scope for future research

The study attempted to verify the structural change to FAHP qualitatively. Future studies can be conducted with more number of evaluators to observe its validity. Additionally, the case of automobile can be extrapolated to other sectors to check any difference. The results of structural transformation FAHP can be further tested and validated through qualitative and empirical studies. The studies may also consider other factors associated with complexity and cost/benefit while evaluating and selecting a supplier from a strategic view. The suggested altered mechanism can be incorporated in a similar type of other decision-making circumstances, such as an ongoing pandemic where the decision-makers are more than one, the situation is very dynamic, and respondents are located at different locations.

The future scope of the study further lies in establishing the consistency in decision making by employing the proposed structural change to the FAHP as it can facilitate algorithmic developments for machine learning. The study can also be initiated to check the effectiveness of the suppliers chosen through suggestive structural transformation FAHP.

6 Conclusion

An analysis of the extant literature on MCDM, particularly FAHP, suggests that models are tested based on computational approaches disregarding their practical significance. This study developed a FAHP-based supplier evaluation model and applied to a case study to resolve the gap between the fundamental theoretical practice and the application. The literature review indicate supplier evaluation models based on AHP (Saaty 1980) and its different variants or extensions are widely used. The present study highlights the blend of the FAHP-based model and other approaches that can accommodate more than one respondent. In this study, the application of proposed methodology is focused on the unit of analysis composed of suppliers within an Indian automotive company. In the present case, the quality of a supplier receives the highest weight, given a performance-demanding scenario and fierce competition among automobile firms. It helps the original equipment manufacturer (OEM) to satisfy consumer needs and further develop supply chain strategies. Hence, the role of a supplier is significant, from the design of the product or service to the delivery of raw materials. Supplier quality depends on operating funds, infrastructure, employees' skill level, supplies, and raw materials.

Moreover, supplier quality is also influenced by both communication and problem-solving capability, as they have the potential to impact the performance of the entire supply chain. Supplier location has a direct impact on logistics cost and delivery time. In the automotive sector selected for this study, it is observed that some OEMs consider the location of their suppliers in the vicinity of their facilities as one of the essential criteria for selection. It is an ideal situation for companies to improve their performance at the lowest cost. The cost of supplies and delivery time are the other two essential criteria while evaluating the supplier. The cost of supplies also involves the ability of a supplier to negotiate with their suppliers (supplier's supplier) and run the firm's operations on lean principles. The delivery task focuses on the supplier's strength to manage the routes, transportation and timeliness. After-sale services of suppliers to OEM are also considered crucial. It helps estimate the quantity and quality of supplies and their acceptability, whether those lots are partially accepted, fully accepted, or entirely rejected.

In the present study, all these aspects have been considered while proposing the structural transformation in the FAHP approach. The approach also suggests accommodating multiple respondents located at different locations.

This study considers the case of an automobile firm. The case study reinforced the management information model formalization employed through a technological information base. It can help purchase and sourcing managers to accommodate and combine multiple responses on the supplier performance for various factors of evaluation. In summary, the study offers interesting and meaningful implications for purchasing and sourcing researchers and professionals to evaluate the suppliers holistically.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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